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FUSED SALT ELECTRODEPOSITED TiB_2 COATINGS ON HIGH-SPEED STEEL TWIST DRILLS

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September 1987

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Block No. 20

Titanium Diboride

ABSTRACT

Tool life tests were conducted on high-speed steel twist drills coated with TiB_2 by the fused salt electrodeposition process. Test results are presented and mechanisms of tool failure are discussed. Modifications to the fused salt electrodeposition process and the character of TiB_2 coatings are recommended for cutting tools and other applications.

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INTRODUCTION

Titanium Nitride

The cutting tool industry has traditionally sought to extend the life of tools through the use of surface treatments. For example, ~~TiN~~ coatings, applied to tooling by the chemical vapor deposition and physical vapor deposition processes are widely used in the aircraft and automotive industries to improve tool life by providing more wear-resistant surfaces, as well as chemical and thermal barriers to diffusion.[1,2]

Since the hardness of TiB_2 (15-45 GPa) is significantly higher than TiN (16-20 GPa), comparable improvements in tool life and cutting performance with difficult to machine materials are to be expected with TiB_2 coated tools. The problem, however, is the technical difficulty in coating tools with adherent TiB_2 by physical or chemical vapor deposition processes. Deposition of TiB_2 using a fused salt electrolysis process is a viable alternative. This concept was tried out successfully in laboratory trials.[3] The purpose of this report is to evaluate the performance of fused salt electrodeposited TiB_2 coatings on high-speed steel twist drills and to specify any process modifications necessary.

EXPERIMENTAL

A pilot scale fused salt cell was built by HTC Industries, Simsbury, CT. The electrolyte employed in this process was the ternary eutectic of lithium-, sodium-, and potassium-fluoride (FLINAK), melting at 842°F (454°C) with titanium and boron added as fluotitanate (TiF_6) and fluoborate (BF_4), respectively. The fused salt cell was operated under an inert gas enclosure ("dry box").

Four heavy web, 0.25 inch diameter, M33 high speed steel twist drills with a crankshaft ground design and 135° point angles were coated with TiB_2. Principal coating parameters and resultant coating thicknesses are shown, as reported by HTC Industries, in Table 1. The adhesion and integrity of the 0.0005-inch-thick TiB_2 coating was inferior to that of the 0.001-inch-thick coating as shown in Figure 1. This, however, could be the result of inadequate surface preparation prior to plating.

Table 1. FUSED SALT ELECTRODEPOSITION PARAMETERS AND RESULTANT COATING THICKNESS FOR EACH DRILL

Drill ID	Plating Temp. (°F)*	Current Density mA/cm²	Nominal Coating Thickness (in.)
A	1120	10	0.0005
B	1120	15	0.001
C	1120	25	0.001
D	1120	40	0.001
E	- Not Coated - Bright Finish -		
F	- Not Coated - Bright Finish -		

*Time at temperature - approximately 100 minutes

1. *TiN-Coated Tools: A Status Report.* Cutting Tool Engineering, v. 36, no. 1, (January/February), 1984, p. 1-5.
2. ANDERSON, A. E. *Vapor Deposited Coatings Combat Friction and Wear.* Metal Progress, v. 128, no. 3, August 1985, p. 41-45.
3. COUCH, H. T. *TiB_2 Electrodeposited Hard-Faced Coatings for Tools.* HTC Industries, Inc., Contract DAAG46-85-C-0026, Bimonthly Progress Report No. 5, U.S. Army Materials Technology Laboratory, July 27, 1986.

A series of holes were drilled with each drill, until tool failure, into a 0.75-inch-thick AISI 4340 steel, quenched and tempered to a hardness of 44 HRC. Drilled depths were limited to 0.50 inch to prevent the aggravated wear experienced when making through holes. Uncoated drills were similarly tested as a control.

Recommended drilling parameters[4] were not used due to the formation of built up edges on coated tools. However, a 0.004 ipr feed and 30 fpm speed, the recommended parameters for 38 HRC steels, were used. For the uncoated drills, this resulted in a reasonable tool life of ~ 110 holes. All holes were drilled without coolant or lubricant. This was done in order to accelerate tool wear and to minimize coating failure due to thermal stresses.

Cutting force and torque about the spindle axis were monitored by a dynamometer during all experiments. Drills were considered to have failed or to have been significantly worn when the thrust force of the drill into the workpiece, required to maintain a constant feed rate, doubled its initial value to ~ 400 lbf, Figure 2.

RESULTS

The total number of holes made with each tool when drilled to failure is shown in Table 2. Erosion of the coating at the chisel edge, land, and flute surfaces was noticed after the first hole was drilled with each tool. Land wear of failed tools, both coated and uncoated, was nearly identical (see Figure 3). However, wear in the flute near the lip of coated tools was not similar. Figure 4, which shows the flute wear patterns of drills that failed after 6 and 160 holes, documents the general trend that the extent of flute wear is a function of holes drilled or the total exposure time of the flute to chip flow. Figure 5 shows that coating irregularities, such as those previously shown in Figure 1, were not found to significantly affect flute wear.

Table 2. TOTAL NUMBER OF HOLES DRILLED WITH EACH TOOL

Drill ID	Holes Drilled
A	180
B	6
C	34
D	160
E	110
F	106

Residual traces of the coating were found in the flute wear zone. Figures 6 and 7 show qualitative element identifications for drills A and B after tool failure in the flute wear zone in the flute, but 1.5 inches from the chisel edge, respectively.

Figure 8 shows a similar trace for drill D and the presence of K, Na, and Si can be seen in the unaffected coating. Since the electrolyte employed is nominally the eutectic of lithium-, sodium-, and potassium-fluorides, the presence of K and Na is expected. The source of Si cannot be explained. In addition, from the relative Ti/Fe line intensity ratios it appears that in this section the TiB_2 coating is thinner.

4. Machining Data Handbook, Machinability Data Center, Cincinnati, OH, 1980, p. 3-15.

Figures 9 through 12 show SEM photographs of the coatings for drills A through D, respectively. For drills A through C, coating roughness and electrodeposited particle size increased with increasing current density. The overall smoother morphology of the deposited particles and overall adherence of the coating on drill D appears to be superior to that of the others, possibly due to different salt and coating chemistries. High points of deposited particles or asperities in the coating appear to have fractured preferentially, as can be seen in samples taken progressively closer to the cutting edge.

DISCUSSION

Even though the bulk TiB_2 coating was worn away from the cutting edge after only a few holes had been drilled, a residual effective coating thickness which penetrates into the substrate appears to remain. This additional affected surface, as evidenced by the EDAX results which show Ti lines even though no coating is present, appears to continue to resist abrasive wear even after the macrocoating has been destroyed. This effect is similar to that which is believed to occur in ion implated and TiN coated cutting tools due to the interdiffusion of the deposited atomic species into the substrate.

The increase in tool life of TiB_2 coated drills A and D, over the uncoated bright finished drills E and F is not considered to be statistically significant. This is due to the small sample size tested. A sampling of at least 30 precision ground drills, for each set of coating conditions, would be required for a valid test.

Since the normal tempering temperature of high-speed steel is in the range of 325°F to 1060°F, fused salt electrodeposition process temperatures should have been kept below 1000°F and time at temperature should not have exceeded 30 minutes. The thermal cycle to which the drills were exposed during the coating process employed in this study is therefore expected to have had a deleterious effect on tool life.

The 0.001-inch-thick coatings tested in this study are considered too thick. As coating thickness increases, coatings become an entity in themselves and tend to fracture, crack, and spall under thermomechanical stresses. Coating thicknesses in the range of 0.00015 inch to 0.00025 inch, commonly found on TiN coated tools, are recommended. Reduced coating thicknesses are also expected to enable lower process temperatures and shorter process times to be used, therefore reducing the potential for substrate damage due to overtempering. The 0.0005-inch-coating thickness of drill A may, therefore, have contributed to its relatively long tool life.

The lower inclination angle of deposited particles on drill D contributed to the superior performance of this drill. Low inclination angles not only indicate good adherence but also reduced stress concentrations, which act as initiation sites for coating failure.

Unexplained differences in surface topography (drills A through C versus drill D), coating thickness (drills A through D), coating chemistry (drills A through C versus drill D) and tool life (drills A and D versus drills B and C), with respect to the primary reported process parameter (current density), indicate poor process control and/or the failure to record or report valid process parameters during fused salt electrodeposition.

CONCLUSIONS

Tool life tests of high speed steel twist drills coated with TiB_2 by the fused salt electrodeposition process were conducted. The statistical significance of those coated drills which out-performed uncoated bright finished drills may indicate a trend, but is doubtful due to the limited number of drills evaluated. Overtempering of the substrate due to excessive plating process temperatures and times may have been the cause of the short tool life observed for other drills.

Although coating wear at the chisel edge, land, and flute surfaces was immediate during the first hole, residual effects of the coating appear to continue to resist abrasive wear.

The thickness range of TiB_2 coatings should be between 0.00015 inch and 0.00025 inch for high-speed metal cutting applications. This is expected to minimize residual stresses and the tendency of coatings to crack and spall under thermomechanical stresses. Secondary benefits to reduced coating thicknesses include lower plating process temperatures and shorter process times, both of which will reduce the potential for substrate damage.

Process temperatures below 1000°F are recommended for high-speed steel tooling. Improved electrodeposition process control, from precleaning uniformity and consistency to the maintenance of salt chemistries, is also required. This is mainly because the character of deposited coatings was found to vary significantly with changes in process parameters.

Future applications for TiB_2 coatings should include low impact, low speed cutting tools such as broaches and high value added items, possibly turbine blades.

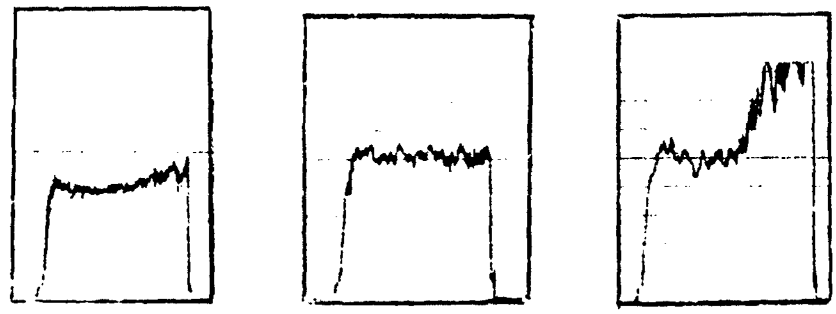
ACKNOWLEDGMENTS

The authors wish to thank Mr. James Buckley for performing the machinability tests and Ms. Gail Meyers for her work on the SEM.

a. The 0.0005 inch TiB_2 coating thickness, drill A

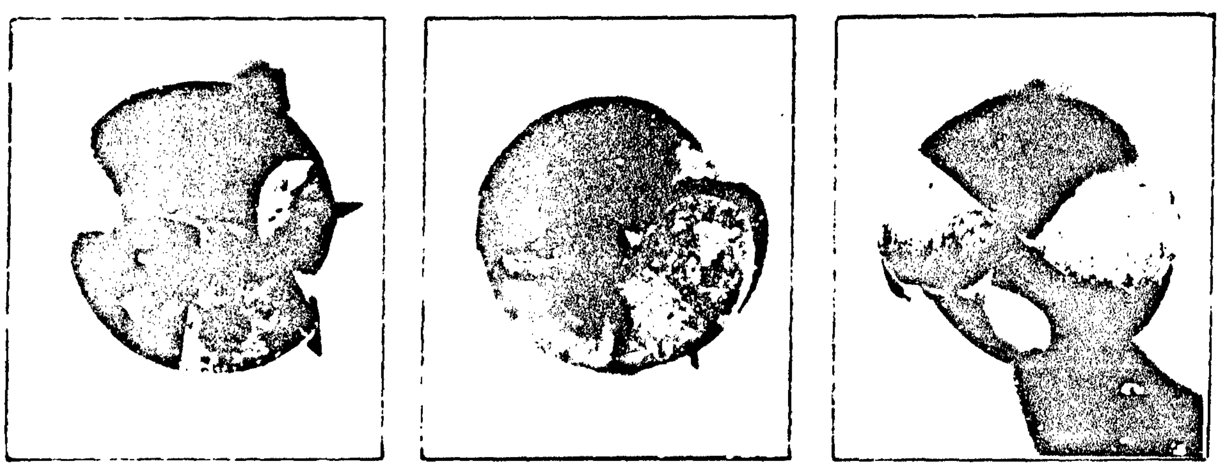
b. A typical 0.001 inch coating thickness, drill B

Figure 1. Photographs showing a higher concentration of surface discontinuities (Mag. 7.5).



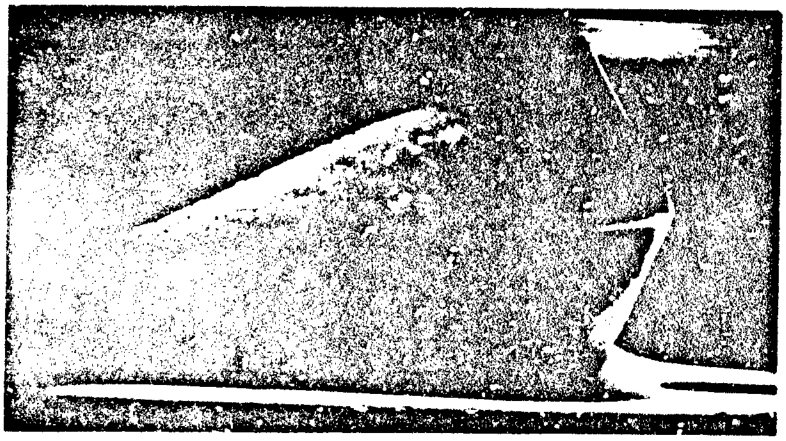
a. 1 Hole b. 110 Holes c. 180 Holes

Figure 2. Cutting force traces for drill A after 1, 110, and 180 holes were drilled (Scale: 50 lb/div).



a. Drill A (180 holes) b. Drill B (6 holes) c. Drill E (110 holes)

Figure 3. End view of drills showing land wear (Mag. 7X).

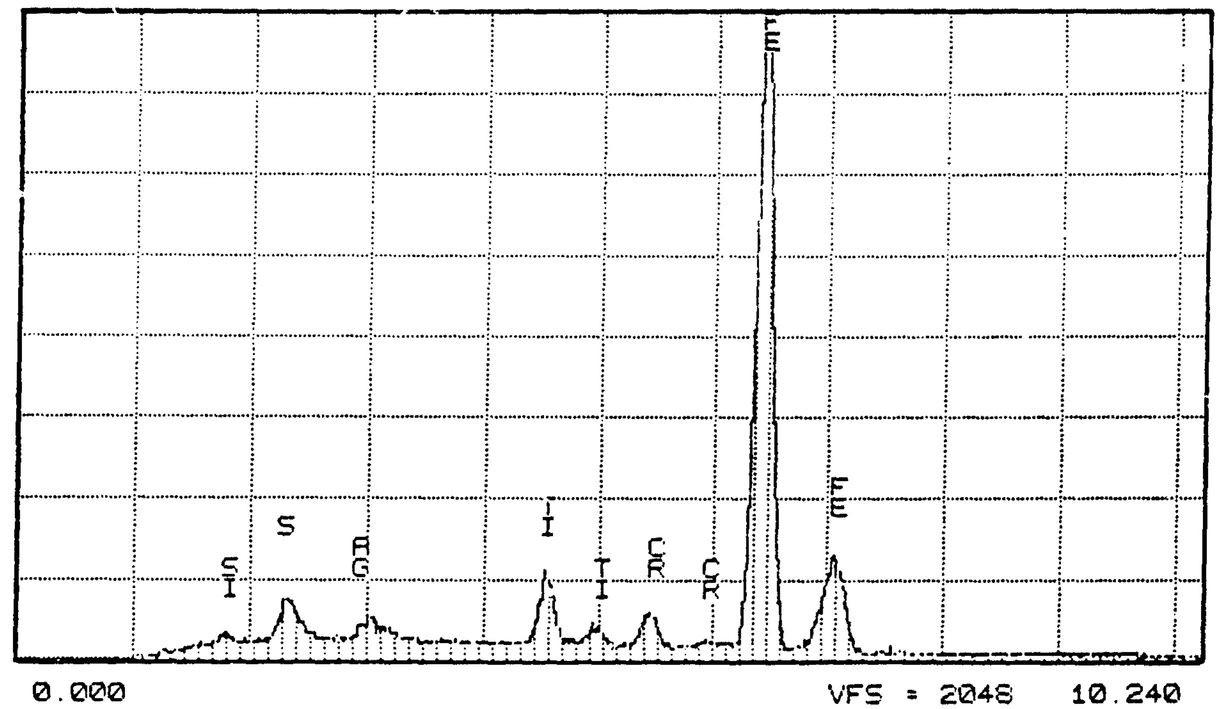


a. Drill B

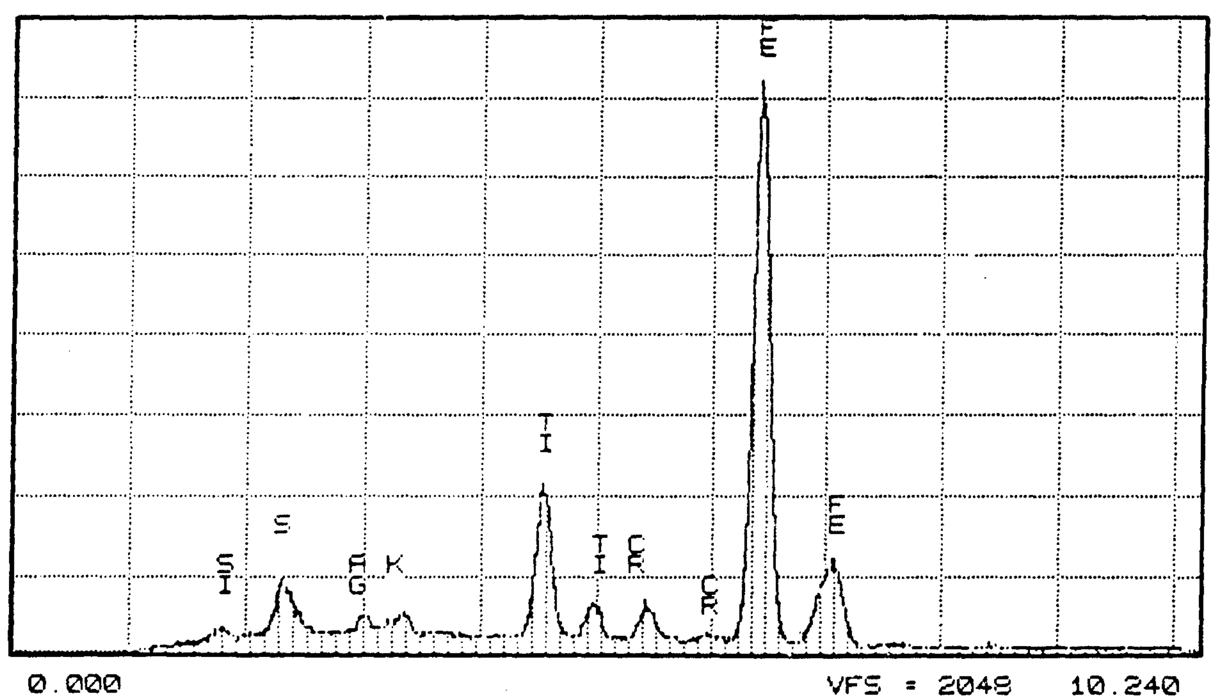
b. Drill D

Figure 4. Flute wear patterns shown by scanning electron micrography (Mag. 10X).

Figure 5. Flute wear pattern of drill A after tool failure, SEM (Mag. 10X).

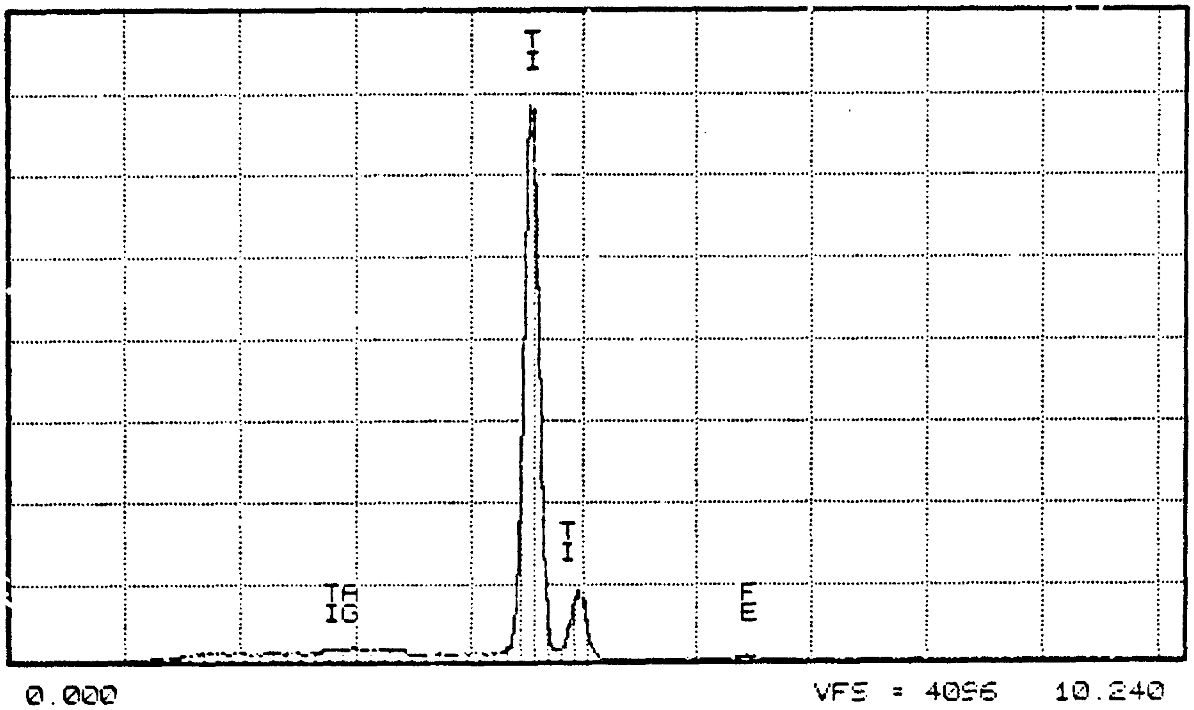


a. Drill A

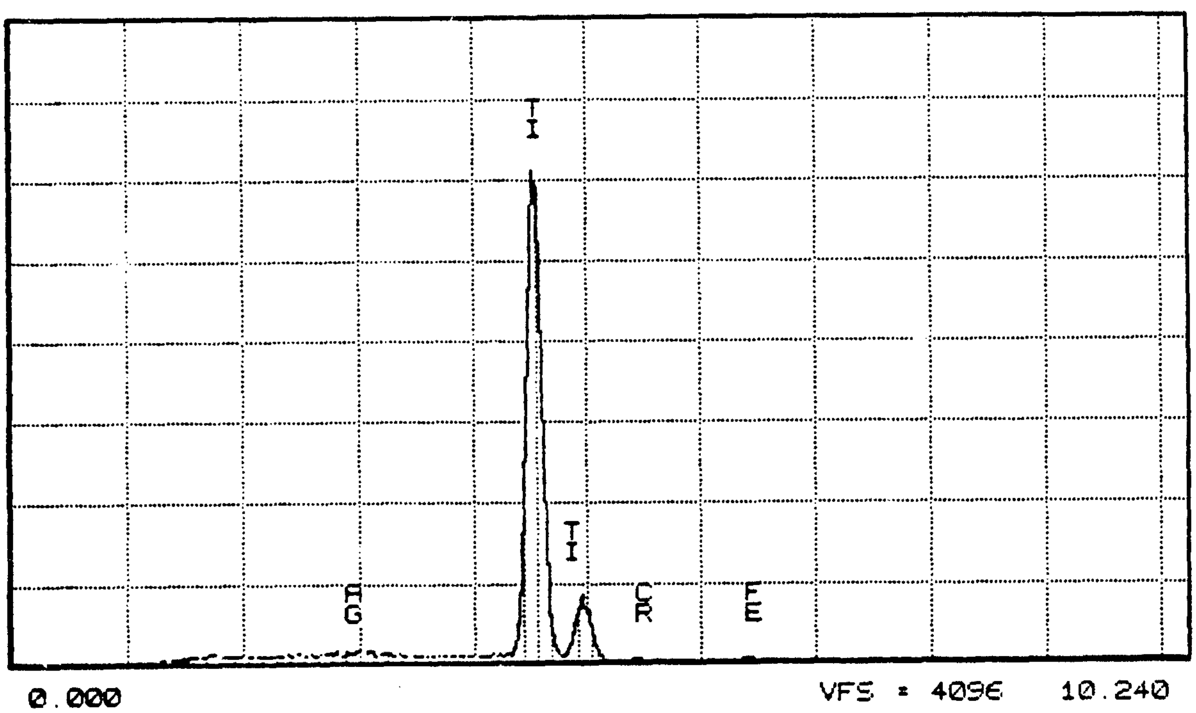


b. Drill B

Figure 6. Qualitative element identification in the flute wear zone.

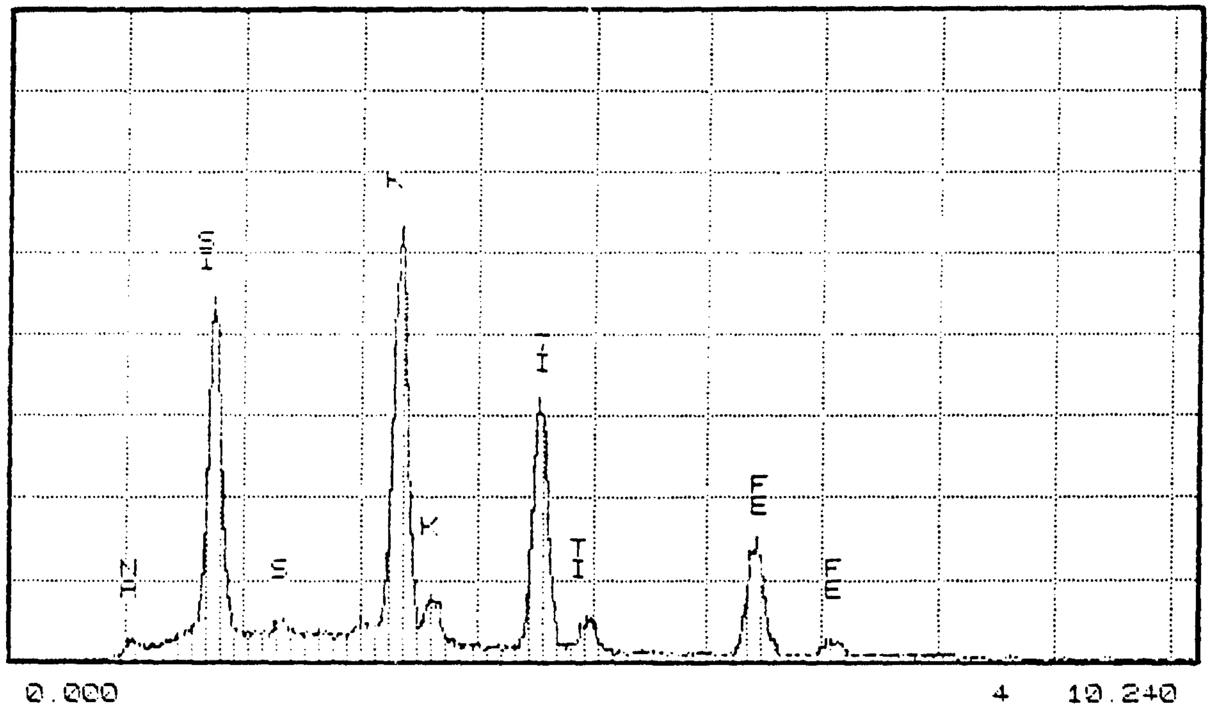


a. Drill A

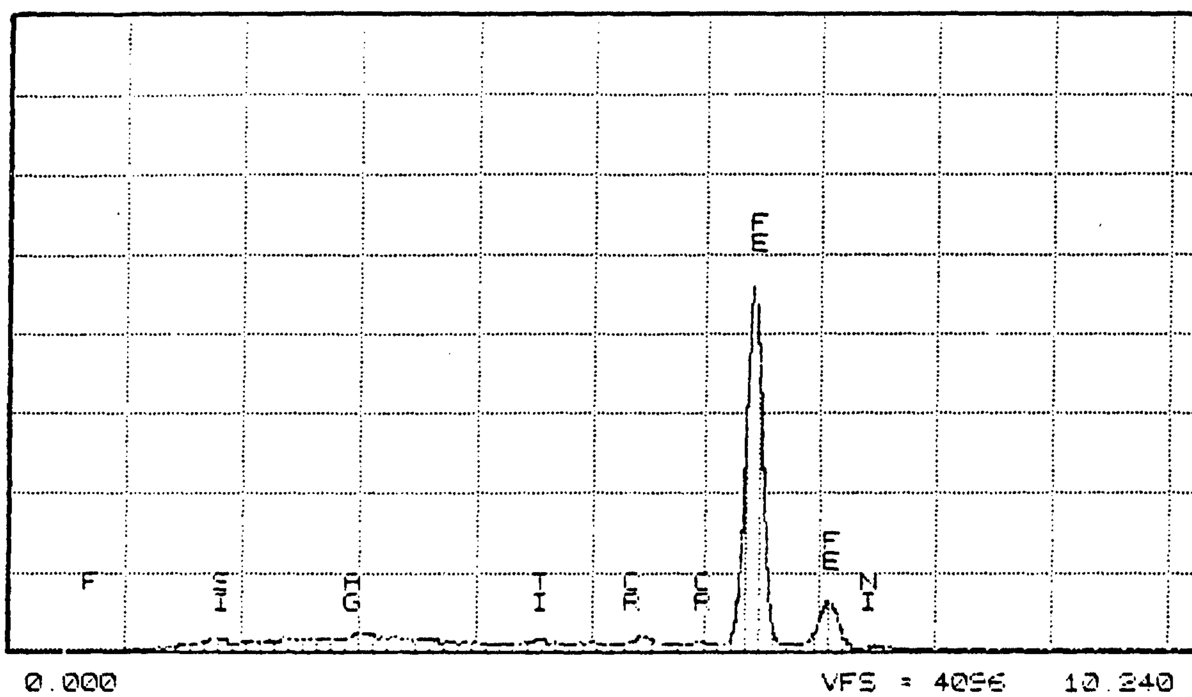


b. Drill B

Figure 7. Qualitative element identification in the unaffected flute area.

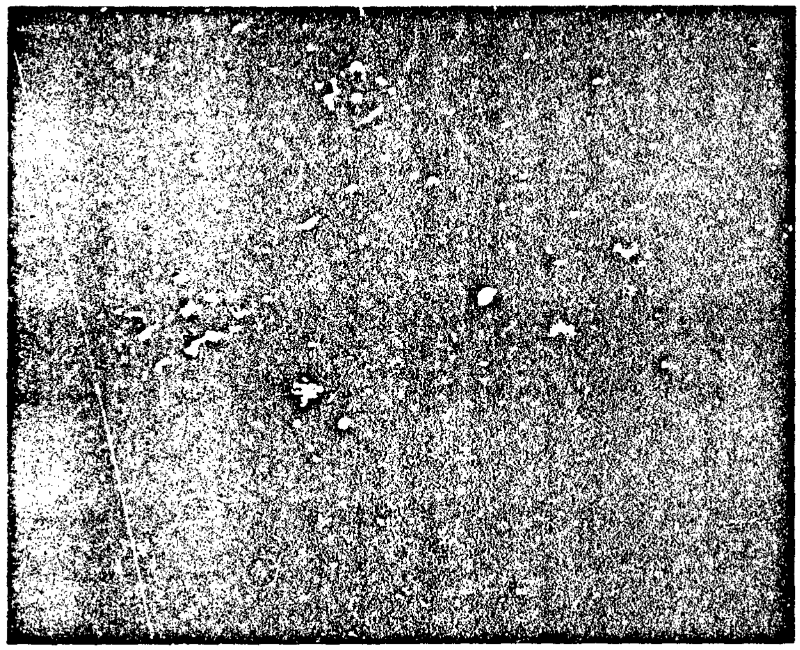


a. 1.5 Inches from chisel point

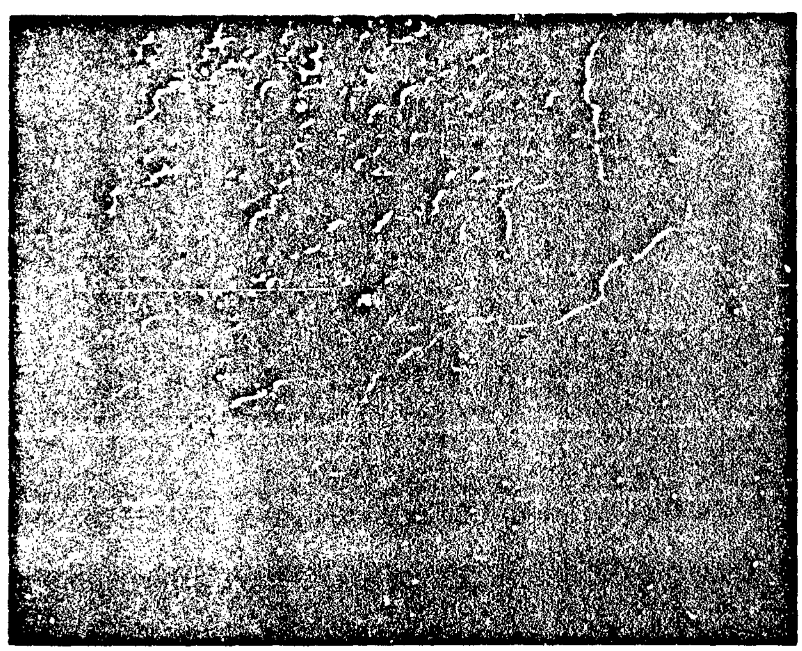


b. The flute wear zone

Figure 8. Qualitative element identification for drill D.



a. Away from the cutting edge of drill A



b. Close to the cutting edge of drill A

Figure 9. SEM photographs (Mag. 1000X).

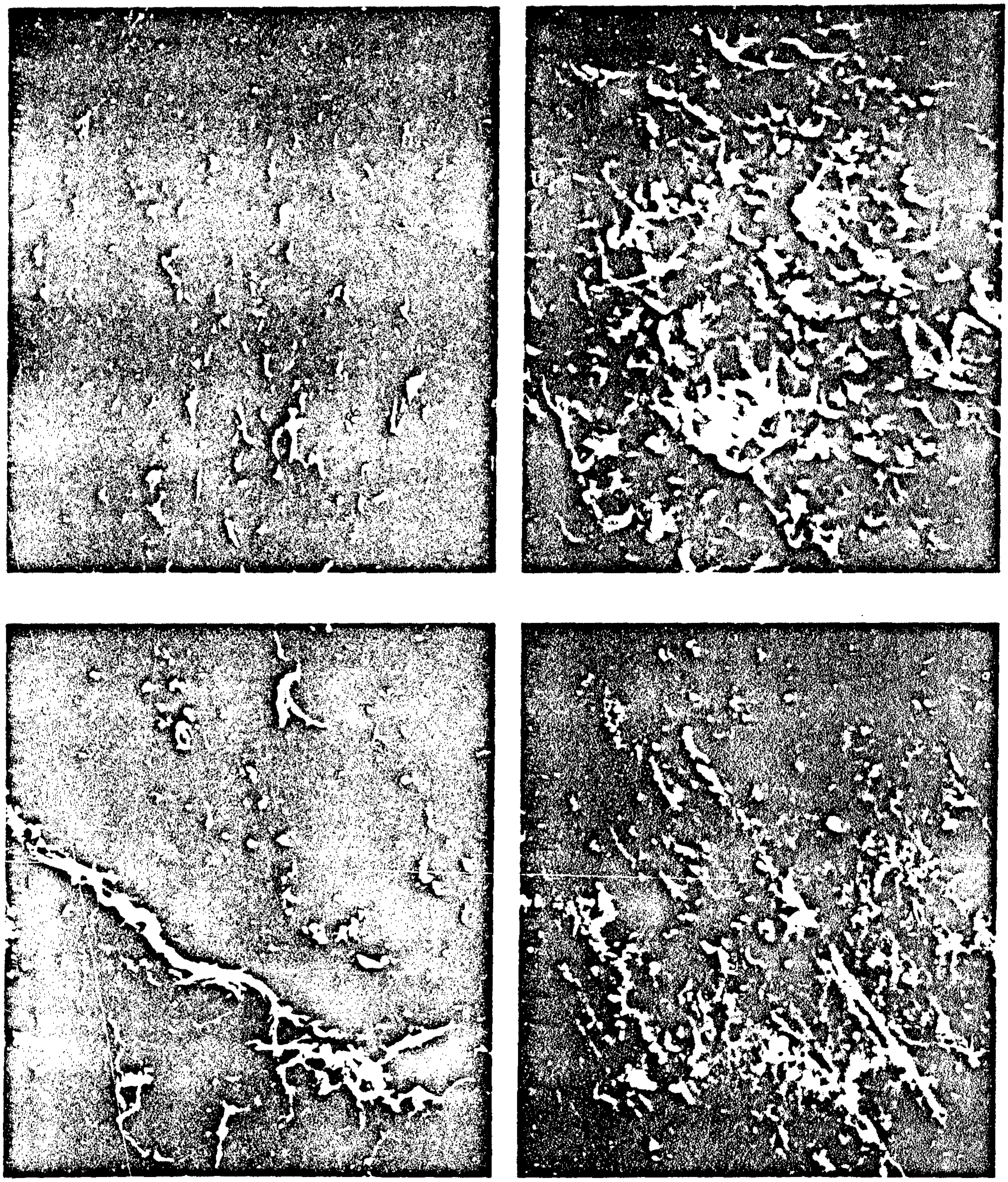
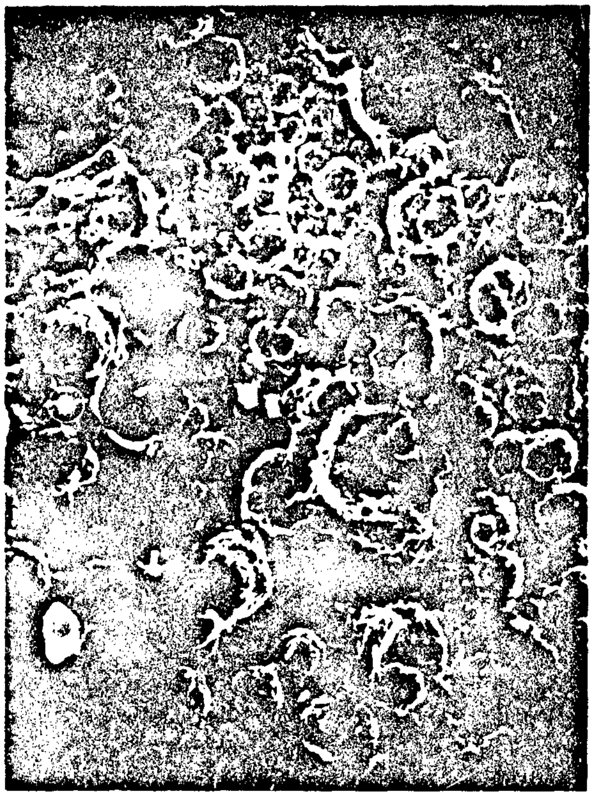


Figure 10. SEM photographs of the TiB_2 coating taken progressively closer to the cutting edge of drill B (Mag. 1000X).



a. Mag. 250X

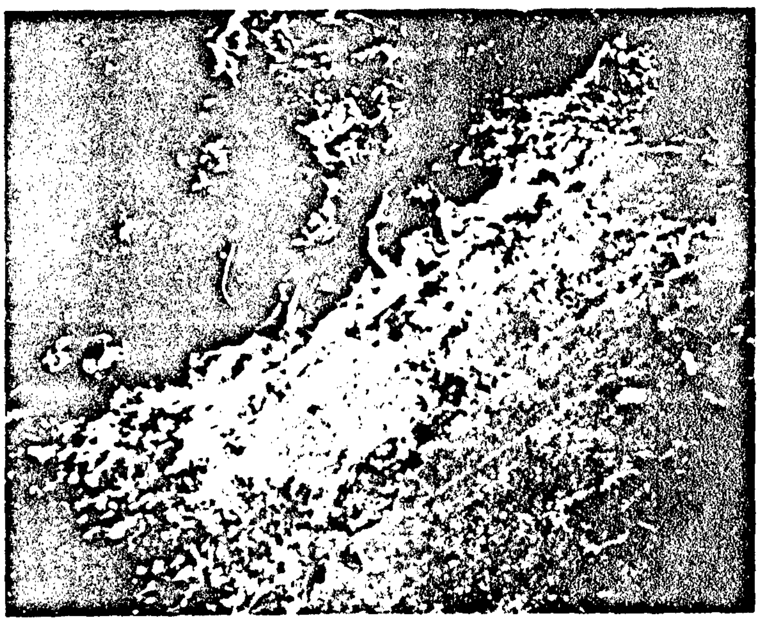
b. Mag. 1000X

c. An area closer to the cutting edge where asperities of the coating have fractured on drill C (Mag. 1000X)

Figure 11. SEM photographs of the unaffected coating.

a.

b.



c.

Figure 12. SEM photographs of the coating of drill D progressing towards the cut edge (Mag. 1000X).

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Technical Report MTL TR 87-48, September 1987, 16 pp - illus-tables, D/A Project 1L263102D077

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U.S. Army Materials Technology Laboratory,
Watertown, Massachusetts 02172-0001
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